Preliminary Flight Deck Observations During Flight in High Ice Water Content Conditions

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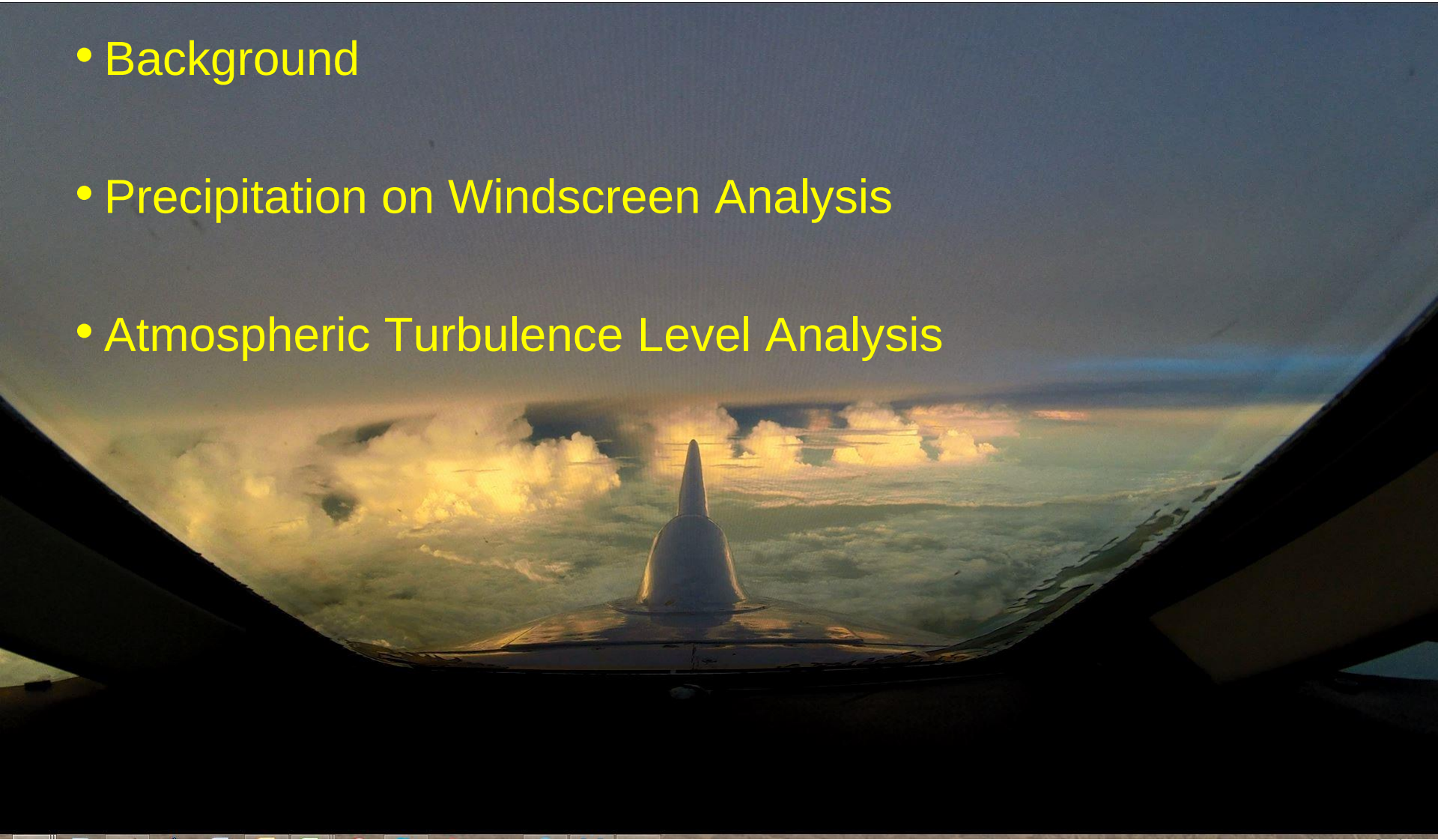
Outline



- Background
- Precipitation on Windscreen Analysis
- Atmospheric Turbulence Level Analysis

Background

List of common observations in engine power-loss events *(from Mason et al, AIAA-2006-0206)*:

- High altitude, cold temperature
- Aircraft in vicinity of convective clouds/thunderstorms
- Significantly warmer that standard atmosphere
- Visible moisture / Instrument Meteorological Conditions
- **Light to Moderate Turbulence**
- **Precipitation on the windscreen, often reported as rain**
- Aircraft total air temperature (TAT) probe anomaly
- Lack of observations of significant airframe icing
- No flight-radar echoes at the location and altitude of the engine event

Background

Since 2006, Mason and others have collected information from pilots via interviews and questionnaires to substantiate earlier observations and support event analyses.

In SAE 2011-38-0094, Mason and Grzych reported

- Vertical acceleration data showed increases in turbulence prior to engine event
  - Pilots reported the turbulence was usually light to moderate, but it was not unique to HIWC clouds
- Pilot observations of rain on the windscreen are varied.
  - Many pilots indicated no rain was observed, while others indicated moderate rain was observed with a unique sound of impacts.
  - Variation in reports may be due to variation in ice concentration, particle size, and temperature

Background

This presentation will show preliminary results using data from the SAFIRE Falcon 20 to substantiate the pre-Darwin pilot observations and analyses of windscreen and turbulence by Mason et al

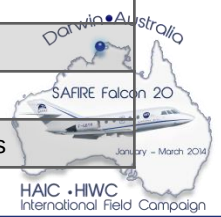
Precipitation on Windscreen Analysis

- Post-Flight Debriefs

- GoPro Hero 3+

Precipitation on Windscreen Analysis

Flight No	Water Streaming	Impact Sound	Max IKP TWC (g/m^3)	Comments
FS140001	N/A	N/A	N/A	Instrument checkout, Question not asked formally
FS140002	Yes	Yes	3.5	Dots on windscreen, loud sound
FS140003	N/A	N/A	2.4	Not clear from debrief notes. TWC mostly < 1.5. only momentary spike to >2
FS140004	No	N/A	2.0	
FS140005	No	N/A	N/A	RASTA / hotwire cal; clear air
FS140006	Yes	N/A	3.8	Water on windscreen associated with higher TWC and updrafts
FS140007	Yes	No	1.5	Less water streaming than previous flight
FS140008	No	No	4.8	Pilots reported seeing ice crystals on windscreen in SAFIRE flt notes
FS140009	No	No	2.1	
FS140010	Yes	Yes	4.0	Water streaming when TWC>2g/m3. Sounds from ice/graupel impacts
FS140011	N/A	N/A	N/A	Transit back from Gove
FS140012	Yes	Yes	5.7	Water streaming when TWC>2g/m3. Sounds from ice/graupel impacts
FS140013	Yes	Yes	4.3	Windscreen totally frozen @ 05:42 Ts=-30C
FS140014	No	No	3.5	Debrief from Gove; No water streaming noted in SAFIRE flt notes too
FS140015	Yes	Yes	4.5	Water streaming when TWC>2g/m3.
FS140016	Yes	Yes	3.8	Water streaming when TWC>2g/m3.
FS140017	N/A	N/A	N/A	Transit from Broome; clear air cal for hotwire probes
FS140018	Yes	No	2.9	Water streaming when TWC>2g/m3.
FS140019	Yes	No	3.7	Light water streaming during IWC peak
FS140020	No	No	n/a	Transit from Broome
FS140021	N/A	N/A	n/a	RASTA cal; clear air
FS140022	Yes	No	3.5	Water streaming during peak IWC and updraft
FS140023	Yes	Yes	4.9	Size of drops correlate with IWC; sounds correlate to larger particles

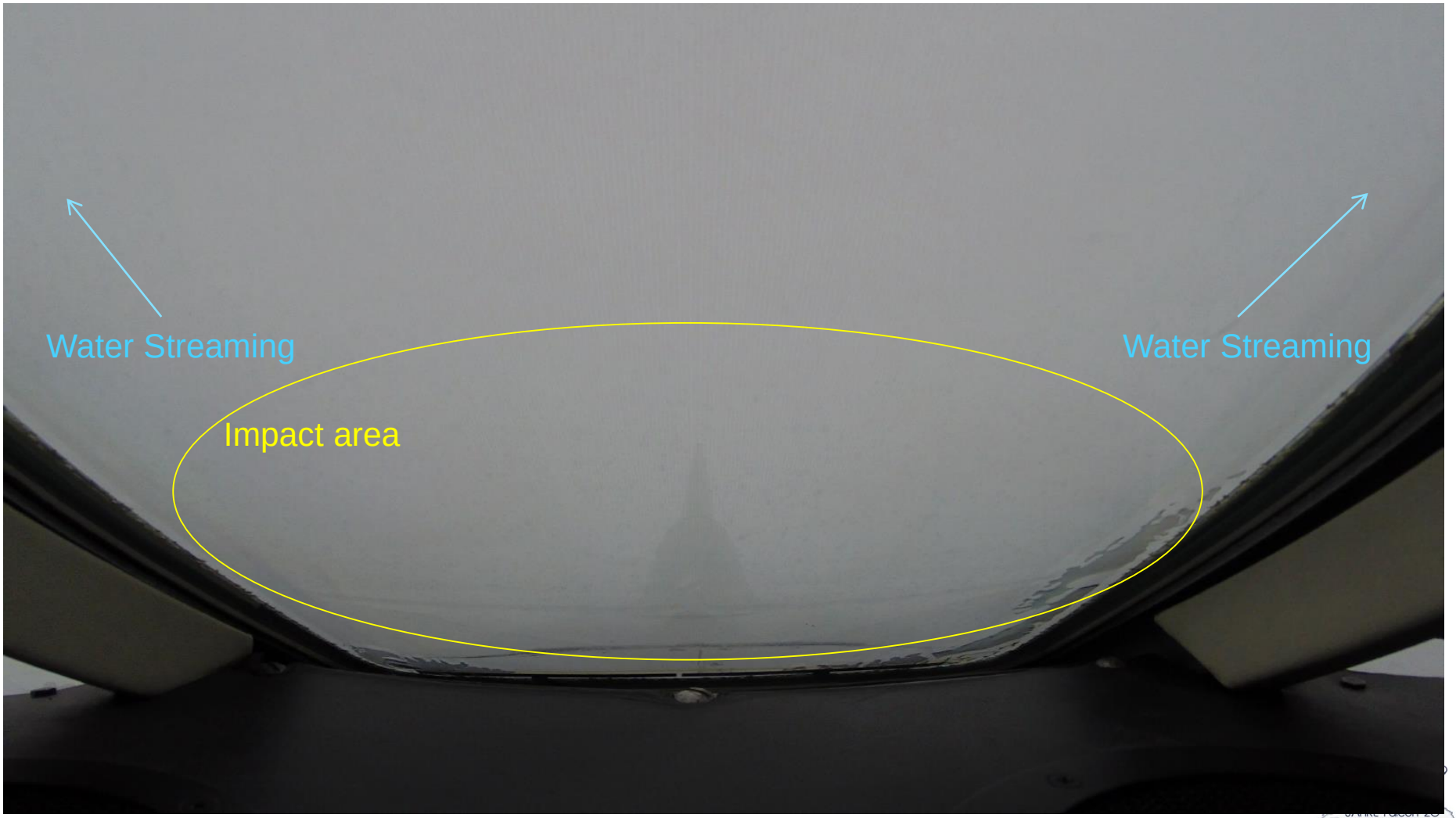


Precipitation on Windscreen Analysis

- Review of Post-Flight Debriefs
  - 12 of 17 flights (70%) in HIWC clouds, pilots reported water streaming on windscreen
  - 7 of 17 flights (41%) in HIWC clouds, pilots reported impact sounds on windscreen
    - Sound usually associated with larger particles or graupel
  - Pilots identified IWC > 2 g/m^3 as a threshold for water streaming
    - 92% of cases when pilots noted YES to water streaming, IWC > 2g/m^3
      - Exception: In FS14007, IWC peaked to 1.5 g/m^3
    - 60% of cases when pilots noted NO to water streaming, IWC < 2g/m^3
      - Exceptions:
        - In FS14008, IWC peaked to 4.8 g/m^3, post-flight report noted ice crystal on windscreen
        - In FS14014, IWC peaked to 3.5 g/m^3

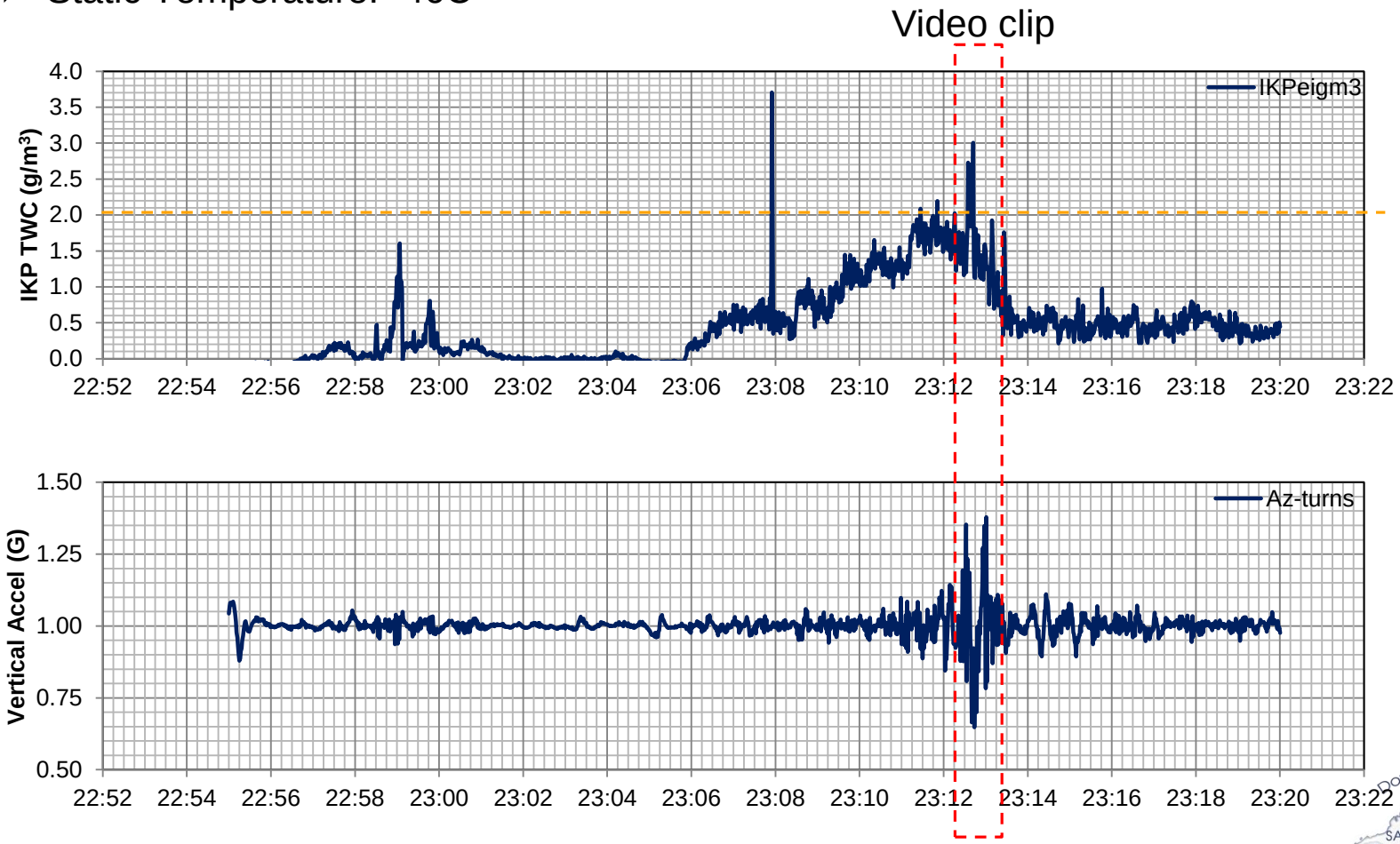
Precipitation on Windscreen Analysis

- GoPro Windscreen Video Example, FS140019, 9-Feb-2014, 23:13 UTC



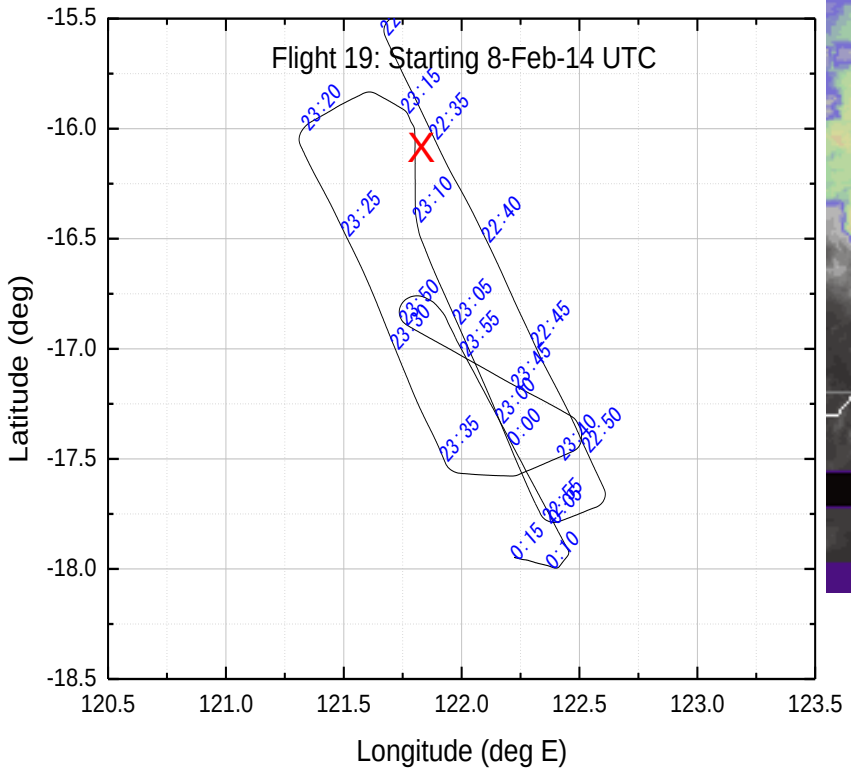
Precipitation on Windscreen Analysis

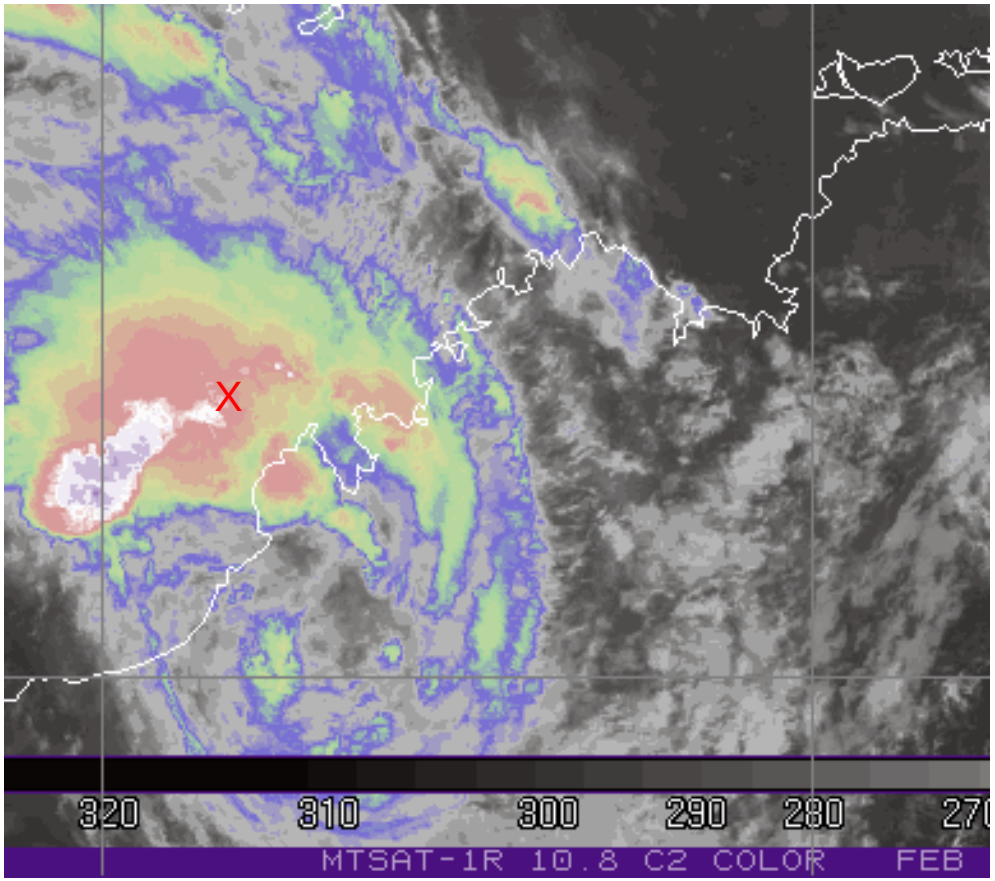
- FS140019, 9-Feb-2014, Run 2
  - Pressure Alt: 38 kft
  - Static Temperature: -46C



Precipitation on Windscreen Analysis

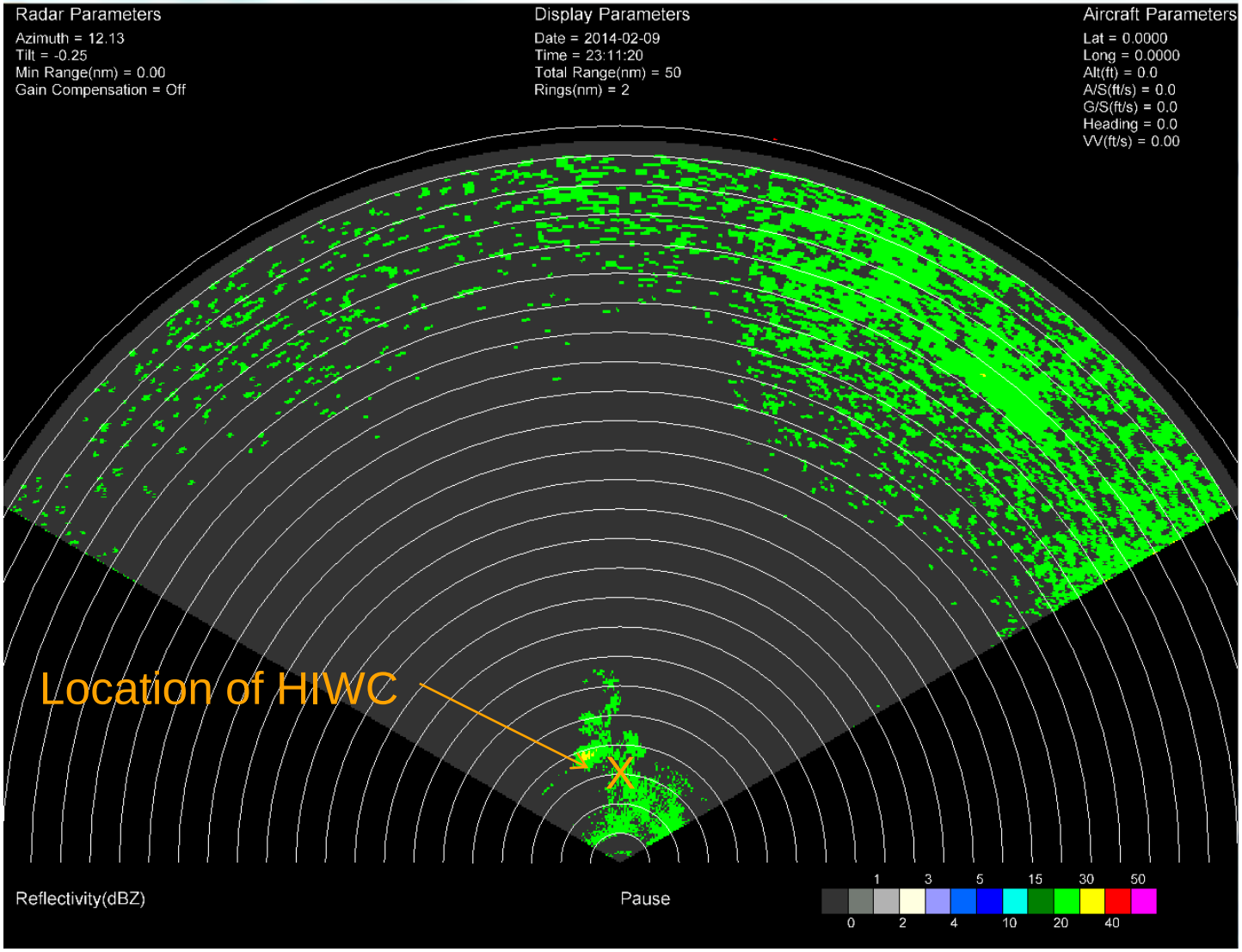
- FS140019, 9-Feb-2014, Run 2





Precipitation on Windscreen Analysis

- FS140019, 9-Feb-2014, Run 2, 23:11 Pilot Weather Radar



Precipitation on Windscreen Analysis

Conclusions:

- Pilot Debriefs:
  - Pilots/flight team identified a useful visual indicator for IWC threshold
  - Pilot debriefs after each flight are a valuable source of information

- Windscreen Video
  - Example case confirms pilot observations of water streaming when IWC > 2 g/m^3
  - Video/audio a valuable source of information to link with other data sets such as TWC, turbulence, weather radar
  - Sound of ice impacts differs from sound of rain impacts

- Way forward:
  - Identify particle images to video/sound
  - Utilize GoPro cameras in future flights
  - Need improved timestamp to synchronize with other data sets

Atmospheric Turbulence Level Analysis

Atmospheric Turbulence Level Analysis

Data sets from SAFIRE

- 1 Hz files (e.g. F20_1Hz-HAIC_base_aipov_v2_20140116_fs140001)
  - vertical acceleration from AIRINS inertial measurement unit
  - True airspeed
  - Angle of attack (α) and angle of sideslip (β) from noseboom
  - Winds (up, north, east) from noseboom
  - etc

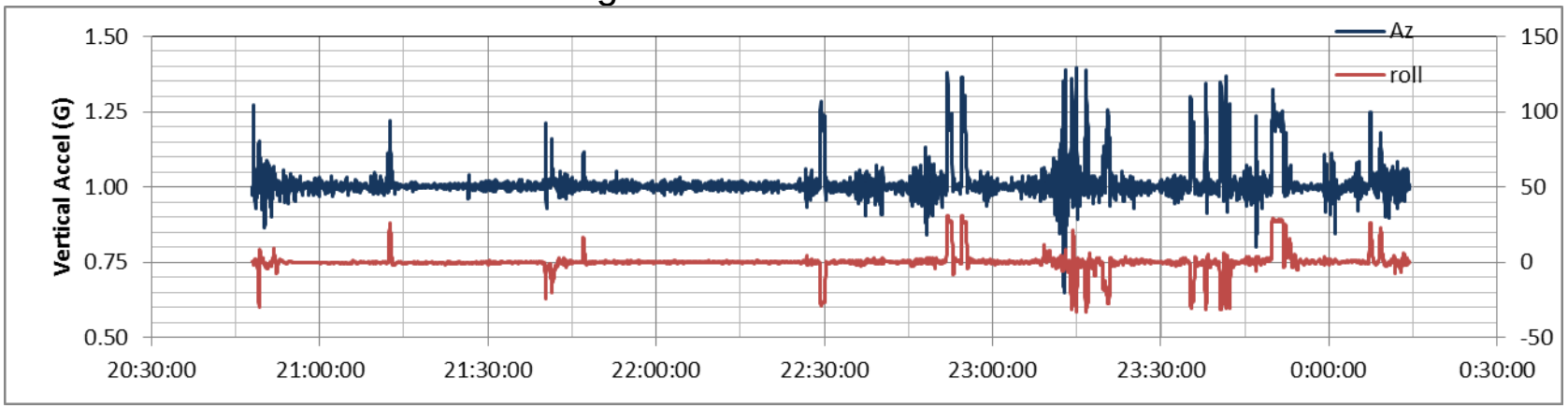
- 5 Hz files (e.g. F20_5Hz-HAIC_RICE_and_angles_20140116_fs140001)
  - Az, Ay, Az accelerations from AIRINS inertial measurement unit
  - True airspeed
  - Angle of attack (α) and angle of sideslip (β) from noseboom
  - RICE
  - Etc

- Post-Flight reports and debriefs

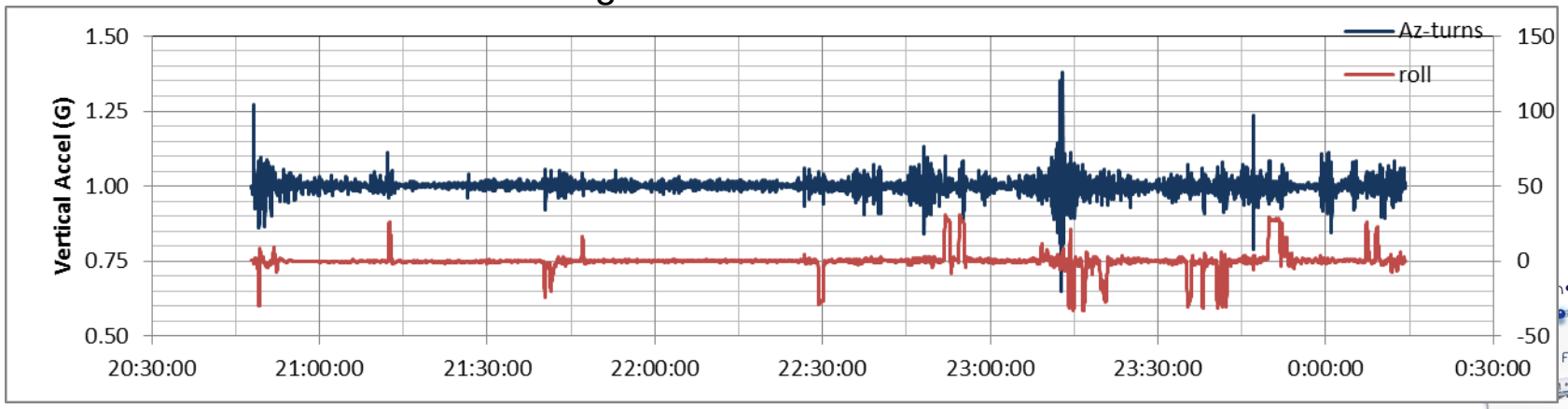
Atmospheric Turbulence Level Analysis

- 1 Hz files processed to:
  - Remove component of vertical acceleration due to turns

Flight 19 no filter for turns

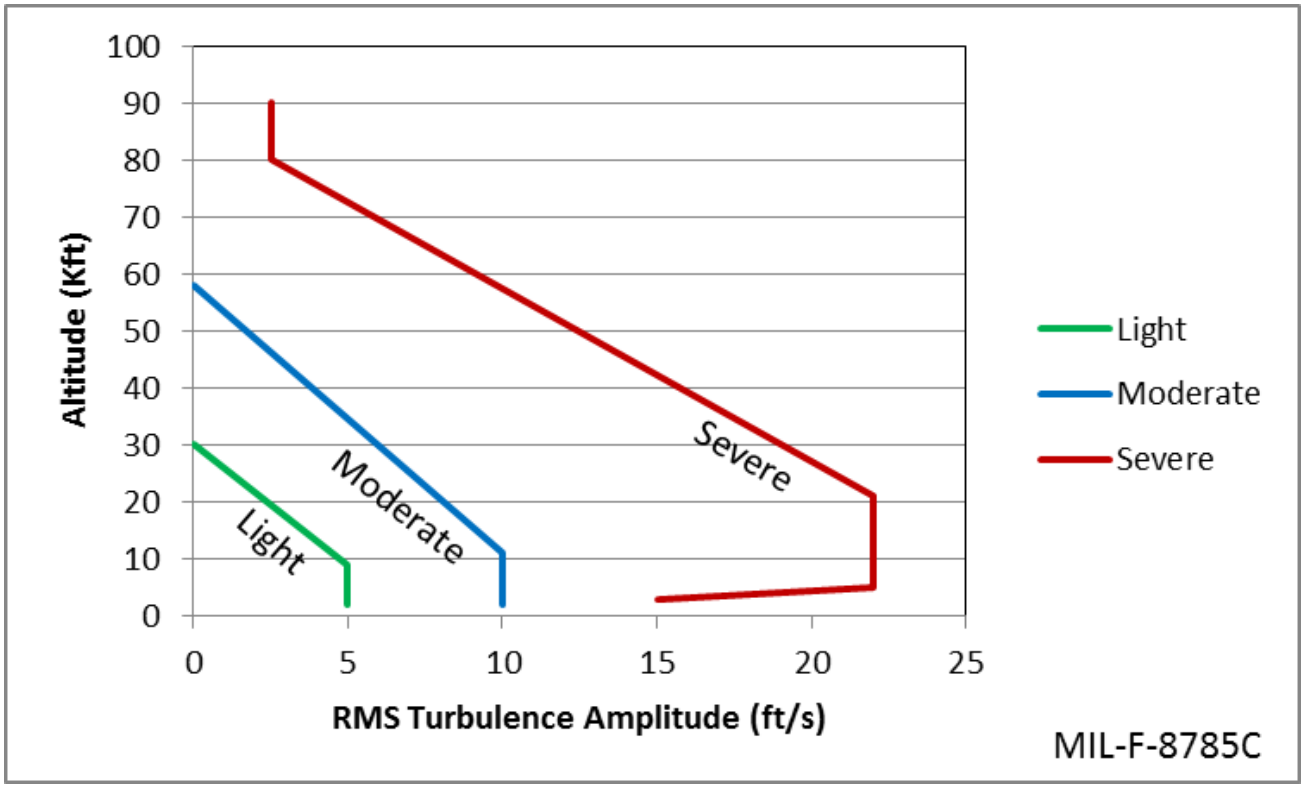


Flight 19 with filter for turns



Atmospheric Turbulence Level Analysis

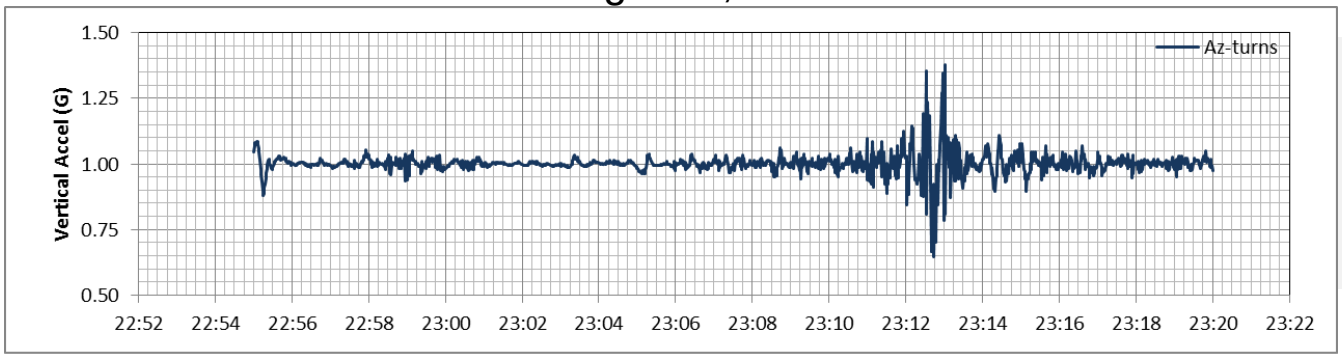
- 1 Hz files processed to:
  - Convert airspeed and flow angles into u, v, w wind components
  - Calculate RMS values of wind components σ_u, σ_v, σ_w (1km distance scale)
  - Apply turbulence level criteria defined in MIL-F-8785C

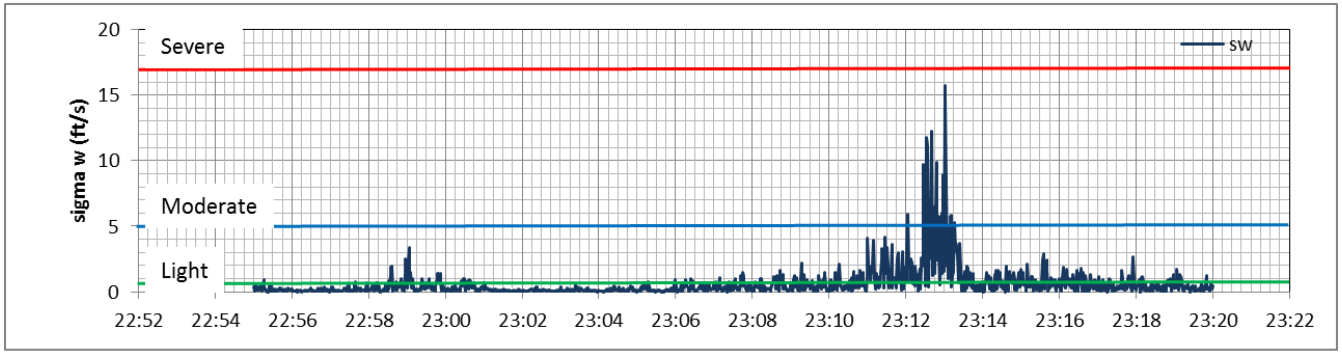


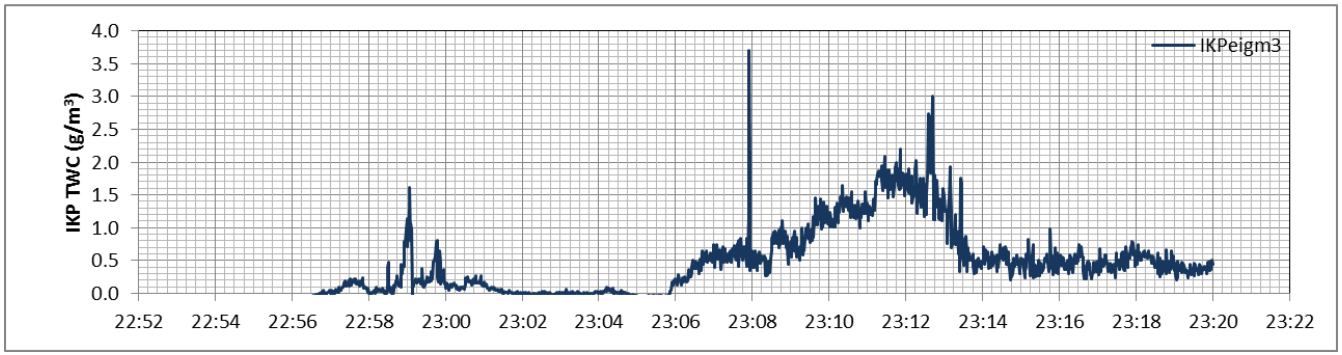
Atmospheric Turbulence Level Analysis

- Reviewed specific runs for each flight per Strapp's initial overview slides

Flight 19, Run 2





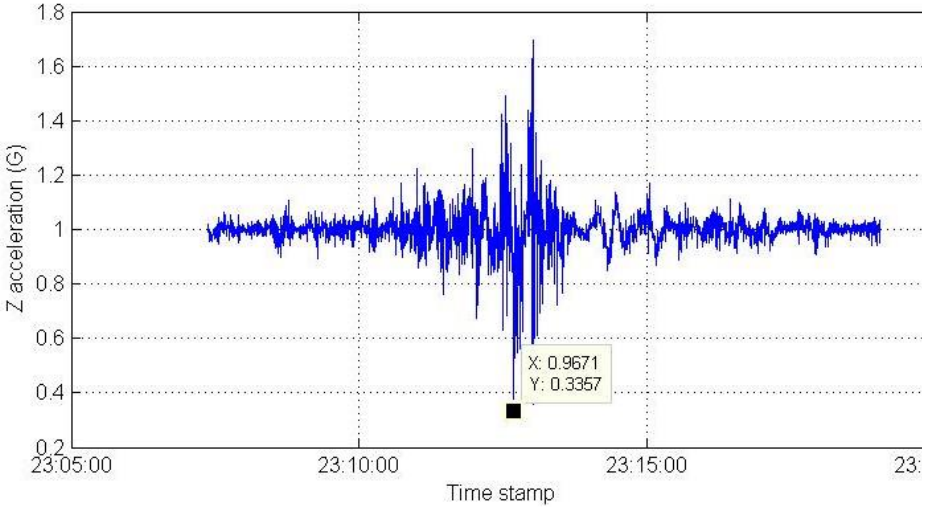


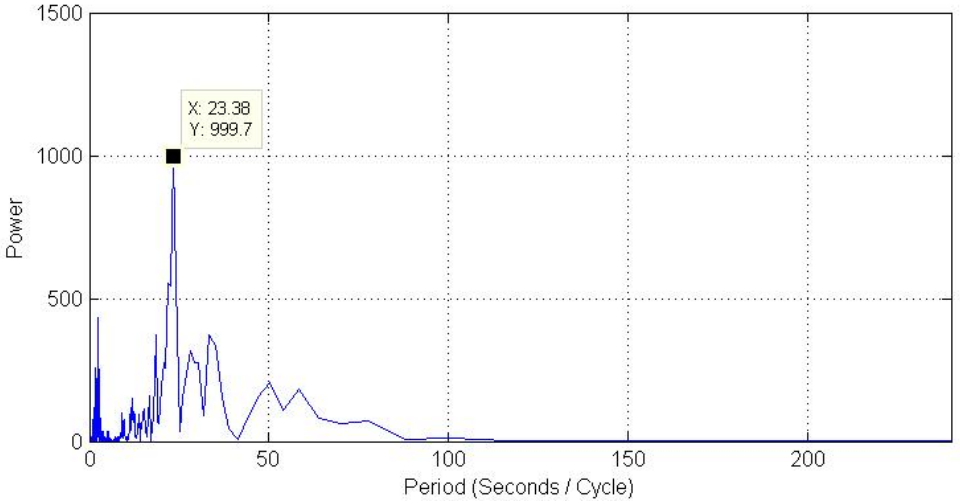
avg (Az)	1.001
std (Az)	0.040
max(Az)	1.378
min(Az)	0.647
peak high	0.377
peak low	-0.354

Atmospheric Turbulence Level Analysis

Analysis of 5 Hz data initiated:

- Specific time periods to be examined based on 1 Hz analysis
  - e.g. Az time history and power spectral density analysis for Flt 19, run 2

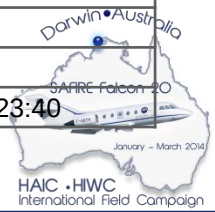




- Peak Az values in 5Hz data exceed 1Hz (~0.3G)
- Peak power indicates some periodicity in Az every 24 seconds for this case

Atmospheric Turbulence Level Analysis

Flight No	Turbulence	Max IKP TWC (g/m^3)	Comments
FS140001	No	N/A	Instrument checkout, Question not asked formally
FS140002	No	3.5	(debrief indicated No)
FS140003	Light/Moderate	2.4	Post-flight report noted a few occurrences of Light to Moderate (debrief indicated No)
FS140004	Moderate	2	Post-flight report noted moderate turbulence @ 24:27 for 20 seconds (debrief indicated No)
FS140005	Light	N/A	Post-flight report noted light turbulence @ 06:56 (debrief indicated No)
FS140006	Moderate	3.8	Post-flight report noted moderate turbulence @21:12, 21:47, 22:45, 22:55
FS140007	Light	1.5	Post-flight report noted light turbulence @20:34 and moderate @ 22:11
FS140008	Moderate	4.8	Post-flight report noted moderate turbulence @21:35, 22:11, 22:40 (debrief indicated No)
FS140009	No	2.1	Post-flight report noted light turbulence prior to landing 23:34 (debrief indicated No)
FS140010	Moderate	4	Post-flight report noted light turbulence @ 21:27, moderate turbulence @21:42, 21:51. Debrief noted moderate plus. Autopilot disconnect, climb 3000 in updraft. Highest turbulence so far.
FS140011	No	N/A	Transit back from Gove
FS140012	Light/Moderate	5.7	Post-flight report noted multiple occurrences of light and moderate turbulence. Debrief noted mostly light
FS140013	Moderate	4.3	Post-flight report noted moderate turbulence @ 05:12 (debrief noted mostly light).
FS140014	Moderate/Heavy	3.5	Post-flight report noted multiple occurrences of light and moderate turbulence. Moderate-heavy turbulence @ 23:03. Heavy turbulence @ 23:09. Debrief noted light-moderate over smaller cells
FS140015	Moderate/Heavy	4.5	Post-flight report noted multiple occurrences of light and moderate turbulence. Moderate-heavy turbulence @ 25:48. Debrief noted moderate near cells
FS140016	Light/Moderate	3.8	Post-flight report noted light turbulence @22:20 and moderate @ 22:27, 23:19 in new cell
FS140017	No	N/A	transit from Broome to Darwin - clear air calibrations for hot wire probes.
FS140018	Light/Moderate	2.9	Post-flight report noted mostly light turbulence with few moderate turbulence.
FS140019	Moderate/Heavy	3.7	Debrief noted moderate to vigorous at FL380 (leg 4, last cell with IWC peak)
FS140020	No	n/a	Transit from Broome
FS140021	No	n/a	RASTA cal; clear air
FS140022	Light/Moderate	3.5	Post-flight report noted occasional light and moderate turbulence (23:12, 24:00)
FS140023	Light/Moderate	4.9	Post-flight report noted light turbulence @ 22:18 and moderate turbulence @ 22:23, 23:40



Atmospheric Turbulence Level Analysis

Conclusions:

- From 1 Hz analysis:
  - Revealed peaks in IWC generally correlated near peaks in turbulence, vertical acceleration, and updraft velocities
  - Identified specific time periods for further analysis using the higher frequency (5 Hz) data
  - Turbulence levels (based on MIL-F-8785C) mostly in the light-moderate and range, and few occurrences of moderate-severe.
- From 5Hz analysis:
  - Peak vertical accelerations in 5 Hz are significantly greater than 1 Hz
  - Power spectral density may identify characteristic time (distance) of turbulence
- From review of post-flight report/debrief
  - Most flights in light-moderate to moderate range with few occurrences of moderate-severe
  - Some inconsistencies between flight reports and debriefs

Atmospheric Turbulence Level Analysis

Way Forward:

- For 1 Hz data:
  - Develop method to objectively categorize turbulence levels for a specific run.

- For 5 Hz data:
  - Examine time histories and PSD of other acceleration axes (A_X and A_Y) and turbulence parameters σ_u, σ_v, σ_w
  - Compare flights to identify correlations

- Document results!